ARIZONA DEPARTMENT OF TRANSPORTATION

SOIL EROSION AND DUST CONTROL ON ARIZONA HIGHWAYS

Part II Laboratory Testing Program

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INTERIM FINAL REPORT

SOIL EROSION AND DUST CONTROL ON ARIZONA HIGHWAYS

PART II - LABORATORY TESTING PROGRAM

by

HASSAN A. SULTAN

Submitted to

The Arizona Department of Transportation
Highways Division
Phoenix, Arizona 85007

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16. Abstract

Forty-six commercially available chemicals were tested in this study. Laboratory testing included subjecting specimens of a dune sand, treated with spray-on chemicals, to simulated wind velocities up to 90 mph. Specimens of compacted granitic soil, treated with either a spray-on or a mixed-in application of the chemicals, were subjected to simulated traffic abrasive forces under simulated tire pressures up to 60 psi.

Selected chemical treatments were subjected to various environmental-durability conditions before testing. Durability conditions included freeze-thaw cycles, wet-dry cycles, rainfall-dry cycles, and variation of curing temperatures.

Based upon the results of this laboratory testing phase, several chemical stabilizers were selected for applications in a large scale field testing program

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ABSTRACT

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Based upon the results of this laboratory testing phase, several chemical stabilizers were selected for applications in a large scale field testing program.

KEY WORDS: Chemical Stabilization, Soil Stabilization, Erosion Control, Dust Control, Wind Erosion, Traffic Erosion, Rain Erosion.

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CHAPTER 1

INTRODUCTION

This laboratory testing program was designed to consider and evaluate several parameters in erosion control of trafficable and non-trafficable areas. These parameters include, method of application, cost and rate of application, curing period, curing temperatures, wind velocities, traffic pressure intensity, freezing and thawing cycles, rain erosion, and wet-dry cycles. Response to chemical treatment is determined by measuring the amounts and rates of erosion (soil losses) of the treated soil as compared to untreated soils.

Scope

The scope and objectives of this laboratory investigation are multifold, and are outlined as follows:

1. Screen the commercial market of soil stabilizing agents by contacting major manufacturers, suppliers, and formulators to obtain materials which they recommend as potentially suitable for soil erosion control. Such materials had to satisfy certain requirements regarding their physical and chemical properties along with cost limitations.
2. Select two soils for use in the laboratory tests. A wind-blown sand (dune sand) to be used for wind erosion studies, and a subgrade soil that was used by the Arizona Department of Transportation (ADOT) to be used for traffic erosion studies.
3. Determine the capability of the collected chemicals in reducing wind erodibility of the dune sand using a spray-on application.
4. Determine the capability of the collected chemicals in reducing traffic erodibility of the compacted subgrade soil using spray-on and mixing applications.
5. Determine the durability of the stabilized soils under adverse environmental conditions. These tests are to be limited to the

best performing chemicals as manifested in the preliminary tests. The durability tests are to include wind and traffic erosion tests under freeze-thaw conditions, wet-dry cycles, rain-dry cycles, and variable curing temperatures.

6. Select several chemicals, at the conclusion of the laboratory testing program, to be used in the field tests.

Scope Limitations

The scope of additives to be used include all types of chemical stabilizers available on the market, however, conventional stabilizers such as portland cement, lime, sodium and calcium chlorides, and asphalt are not included. Some petroleum products that can be evaluated as chemical stabilizers were included and tested in this program.

The dilution rate and method of application of the chemicals as used in this study conform as close as possible with the recommendations given by the suppliers. Deviation from these recommendations were made, in some cases, to conform with the cost limitations imposed by the selection criteria.

Accordingly, optimization of chemical properties of the additives and optimization of cost-benefit ratios are excluded from this study. Such optimization studies should constitute a separate investigation in which the potential of very few selected chemicals can be investigated for stabilization of various soils having a wide range of soil properties.

Finally, it is pointed out that the materials compared in this study were commercial items. They were not developed or manufactured to meet any particular Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

CHAPTER 2

MATERIALS EVALUATION

The basic materials used in this laboratory investigation include the soils and the chemical additives. Other materials or equipment used in testing are discussed elsewhere under appropriate headings.

Selection of Soils

Four bulk soil samples were submitted by ADOT for evaluation and selection of a dune sand and a subgrade material. Two sand samples were submitted, one from the Yuma area and the second from the Holbrook area. Two subgrade samples were also submitted, one is a granitic soil from Apache Trail and the second is a volcanic type soil.

Physical and mechanical properties of these four soils were determined in the laboratory including specific gravity, grain size distribution, Atterberg limits, and compaction characteristics. Based on these tests, the Yuma sand and the Apache Trail granitic soil were selected for use in the laboratory phase of the study and about 4-tons of each were delivered by ADOT.

Yuma Sand

This is a wind blown dune sand obtained from Yuma, Arizona. The grain size distribution of this sand is shown in Figure 1. The calculated uniformity coefficient of approximately 2.5 indicates that the sand has a very uniform gradation. Most of the sand grains fall in the size range of 0.1 to 0.3 mm. Physical and mechanical properties including specific gravity, plasticity, and compaction characteristics, are given in Table 1. The chemical analysis including its pH value, different salt and ionic concentrations, and the amount of organic matter is shown in Table 2.

An x-ray diffraction study of the sand was performed as a means of identifying the principal mineral constituents of the soil. The analysis

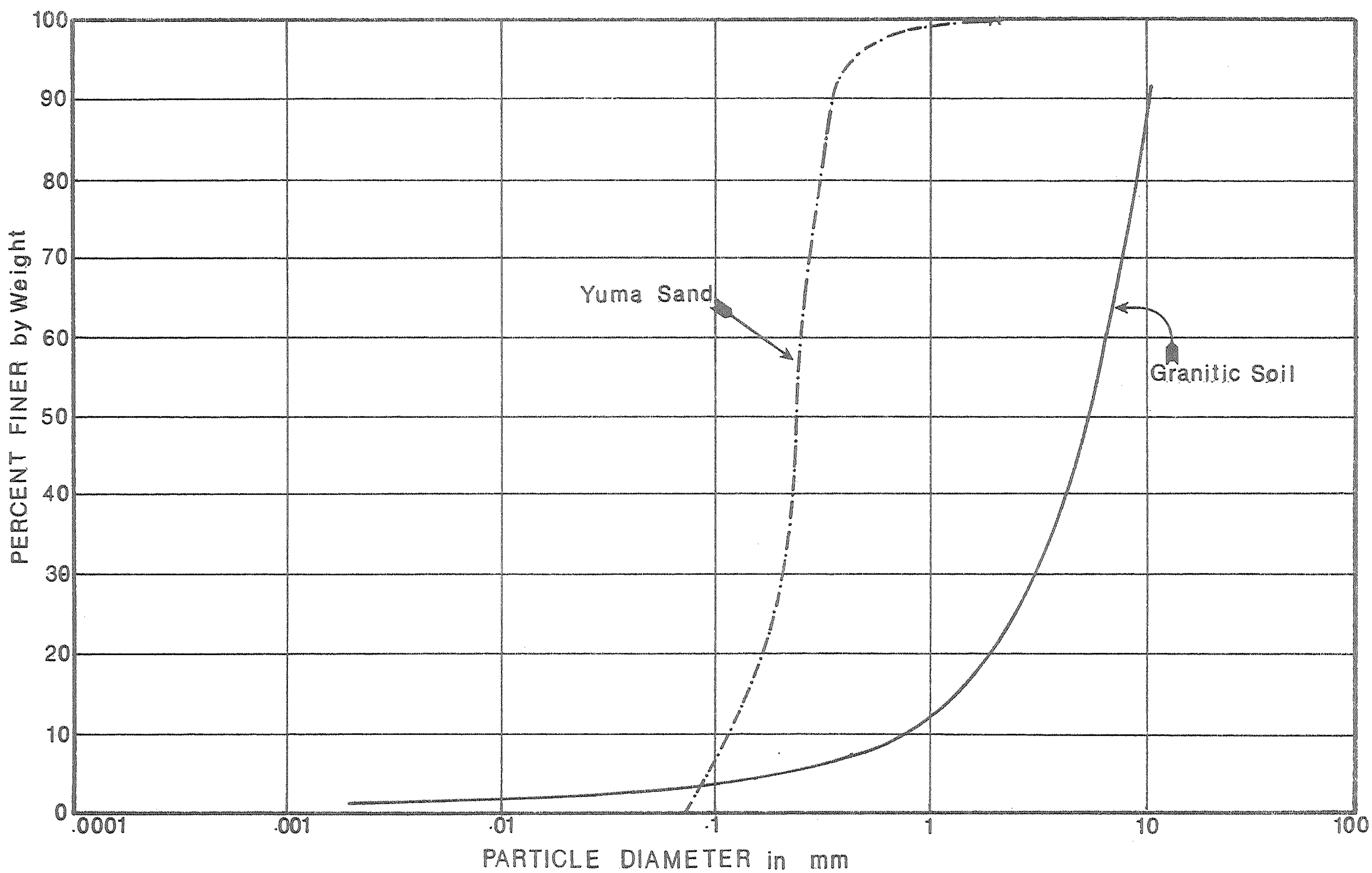

FIGURE 1 - GRAIN SIZE DISTRIBUTION CURVES

TABLE 1 - INDEX PROPERTIES OF SOILS USED

Index Property	Yuma Sand	Granitic Soil
Specific Gravity	2.67	2.70
Liquid Limit %	--	36
Plasticity Index %	NP	5
St. AASHTO, δ max. pcf	105.5	122.3
St. AASHTO, W opt. %	11.8	12.0
Mod. AASHTO, δ max. pcf	110.3	128.5
Mod. AASHTO, W opt. %	11.2	9.4

TABLE 2 - CHEMICAL ANALYSIS OF SOILS

Chemical Property	Yuma Sand	Granitic Soil
pH Value	8.4	6.9
Soluble Salts, ppm	126	98
Nitrates (NO_3), ppm	6.4	5.0
Phosphates (PO_4), ppm	5.8	2.25
Organic Matter, %	0.064	0.22

showed the following minerals to be present in a decreasing order: Quartz (about 80%+), Feldspar (plagioclase), Mica (illite and muscovite), Chlorite, Kaolinite and Calcite.

Granitic Soil

This is a subgrade soil obtained from Apache Trail area (Mile Post 201.2 maintenance pit) and was being used for subgrade construction. The grain size distribution of this soil is also shown in Figure 1. Physical and mechanical properties of this soil are presented in Table 1. Based on these results, the granitic soil is classified as (A-1-a) soil. The chemical analysis including its pH value, different salt and ionic concentrations, and the amount of organic matter, is shown in Table 2. X-ray study of this soil indicated the presence of the following minerals in a decreasing order: Feldspars (orthoclase and plagioclase), Quartz, Dolomite, Mica (illite, muscovite), and Chlorite-Smectite mixed-layer minerals.

Selection of Chemicals

To screen the commercial market of soil stabilizing agents, major manufacturers, suppliers, and formulators were contacted for the purpose of obtaining materials which they recommend as potentially suitable for soil erosion control. Each agency contacted was provided with a letter explaining the scope of the project along with the specific requirements the chemicals should incorporate. These requirements are summarized below under "Stabilizers Criteria". A copy of the material forwarded to these agencies is included in Appendix A.

Stabilizers Criteria

The solicited stabilizers, as applied were required to be products that are non-toxic, non-flammable, non-corrosive to allow easy storage, are easy to handle and apply, and unharmful to plant or animal life should they leach out of the treated soil. The products should be economical to use with a material cost limit not exceeding 15 cents per square yard for stabilization of non-trafficable areas such as embankments and open spaces. Material cost limit of 75 cents per square yard was set as the ceiling value for stabilization of trafficable unpaved roads. These were the proposed initial stabilization costs, with annual maintenance costs not exceeding 5 cents and 10 cents per square yard for non-trafficable and trafficable areas, respectively.

Chemical Solicitation

Approximately 170 manufacturers and suppliers were contacted for the purpose of soliciting chemical stabilizers. Six months later another solicitation letter was sent to the 75 manufacturers and suppliers who did not respond to the first request. A copy of the second letter of solicitation is also given in Appendix A. A list of the companies which were contacted is also given as Table A-1, in Appendix A. Fifty-two companies declined to participate for one reason or another but the majority declined due to unavailability of chemicals that satisfy the criteria given. Seventeen solicitations were returned by U.S. mail apparently for lack of forwarding addresses. Thirty-six companies accepted to participate in the project and forwarded their chemicals. We have received and worked with 45 chemicals. A list of the chemicals used in this project is given in Appendix B with a separate sheet for each chemical giving its name, manufacturer, properties, cost, the rates of dilution and of application used in the laboratory study, along with general remarks and comments, if any. The chemical listed as No. 46 is essentially a mixture of two other chemicals, No. 17 and No. 14, as discussed elsewhere in this report.

CHAPTER 3

LABORATORY TESTING PROGRAM

The laboratory tests conducted were designed to evaluate the capability of the stabilized soils to resist wind erosion and traffic erosion forces, as applicable. Accordingly separate tests were designed for wind erosion and for traffic erosion. This chapter includes a detailed description of these various test methods.

Wind Erosion Tests

The wind erosion tests were conducted to evaluate the degree of stabilization imparted by spraying the chemicals on a wind-blown dune sand when subjected to various wind velocities. Specimens tested for wind erosion studies were not subjected to traffic simulation.

Accordingly, for these tests only the Yuma sand was used, and only a spray-on application of the chemicals was used.

Test Procedure

The molds used in this test, and actually for most other tests, were 6-inch diameter and 2-inch high. The molds were machined from a 6-inch schedule-40 polyvinyl chloride (PVC) pipe. This type of pipe was selected since most chemicals do not bond too well to its surface. The following steps were followed in performing this test:

1. Enough sand was oven dried then allowed to cool down to room temperature under a plastic cover. An empty mold was then placed on top of a 8 in. X 8 in. piece of 3/4-inch thick plywood. The weights of both the mold and the plywood were recorded. A consistent weight of dry sand (1435 gms) was poured into the mold. This particular weight was decided upon after averaging the weights of sand needed to loosely fill up 10 molds. This weight gives an average loose density of about 96.6 pcf. In order to obtain a homogenous sample, another plywood cover was placed on top of the mold and then the mold with the sand in

it confined between the two plywood covers was turned over end for end several times. The mold was then placed flat on a horizontal bench and the top plywood cover removed. The surface of the loose sand inside the mold was level and ready to be sprayed. The weight of the plywood support, the mold and the sand was recorded. Figures 2 through 4 show the steps of placing the sand in the mold.

2. A plywood sheet 18 in. X 18 in. with a 6-inch diameter hole in the center was placed on top of the sample such that the surface of the sand was totally exposed through the center hole. This sheet was used to avoid spraying the mold and the plywood over which the mold was placed with the chemicals.
3. The chemical to be sprayed was prepared at the dilution rate recommended and was placed into the tank of a spray gun. The spray guns used were the bleeder-type with air blowing through the gun constantly. The trigger controls only the flow of the chemical. The air pressure used was varied from one chemical to the other depending on the viscosity of the solution. The nozzles were adjusted to give a uniform spray. The dilution and rate of application for each chemical is given in Appendix B.
4. The surface of the specimen was then sprayed evenly with the chemical. The weight of the sprayed specimen was monitored every now and then until the required amount of chemical spray was sprayed on the surface. The specimen was then removed and placed in a curing room at constant temperature of 70°F and 50% relative humidity. Figure 5 shows a specimen being sprayed; and a section of the curing room is shown in Figure 6.
5. For each chemical treatment three sets of specimens were prepared for each wind velocity used. One set was cured for 1 day, one for 3 days, and one for 7 days. The final weight of the specimen at the end of curing was then recorded.
6. At the end of the specified curing period the specimen was transferred from the curing room and placed in front of a wind blower. Two wind blowers were set up with attachments as shown in Figure 7. The plexiglass attachments were designed to deliver

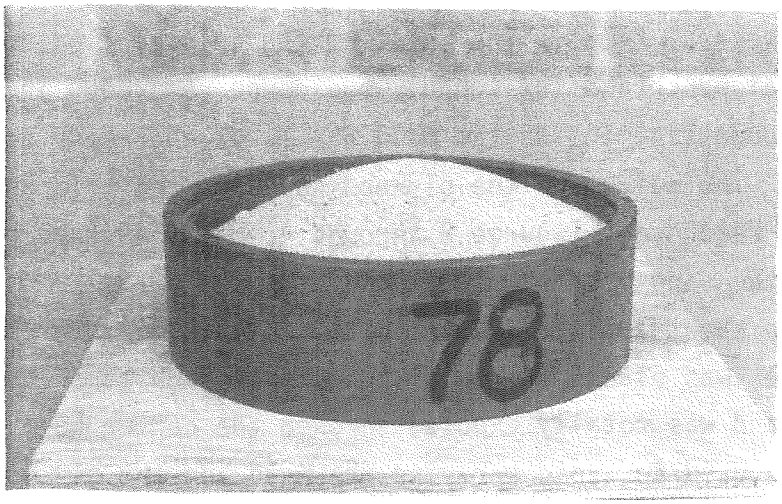

FIGURE 2: LOOSE SAND POURED INTO THE MOLD

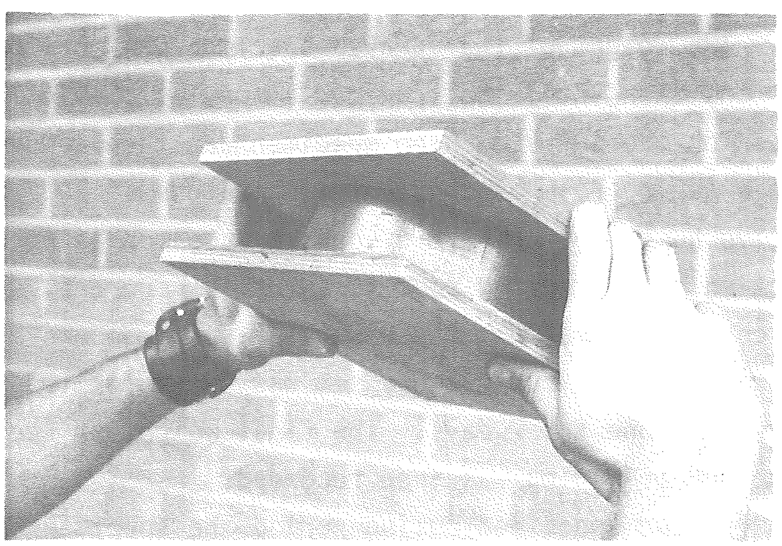

FIGURE 3: TURNING MOLD OVER END FOR END

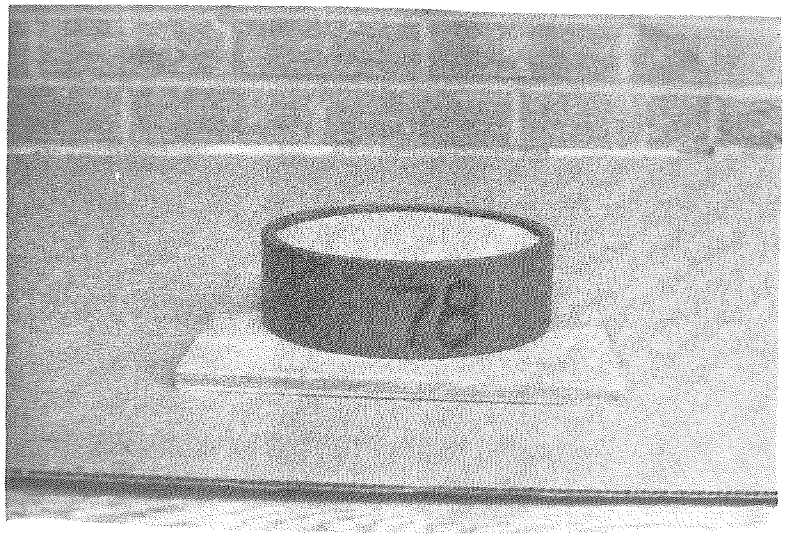

FIGURE 4: LOOSE SAND WITH LEVEL TOP SURFACE

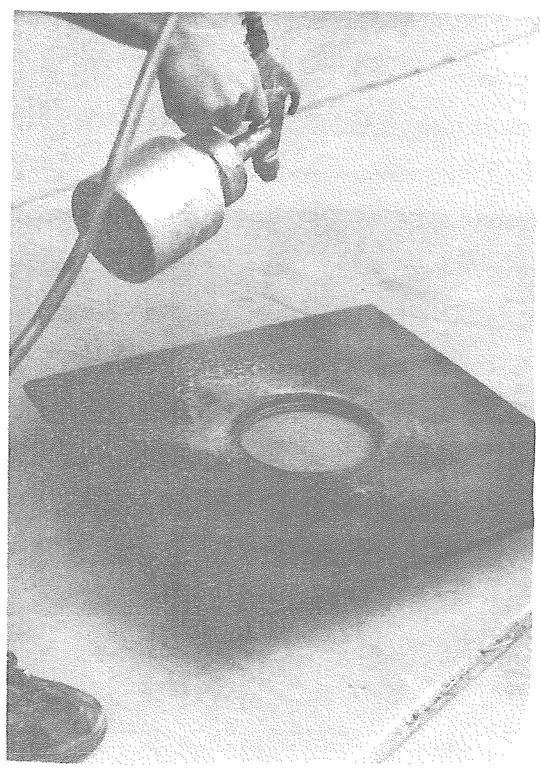

FIGURE 5: SPRAY-ON APPLICATION OF CHEMICALS

FIGURE 6: SPECIMENS IN THE CURING ROOM

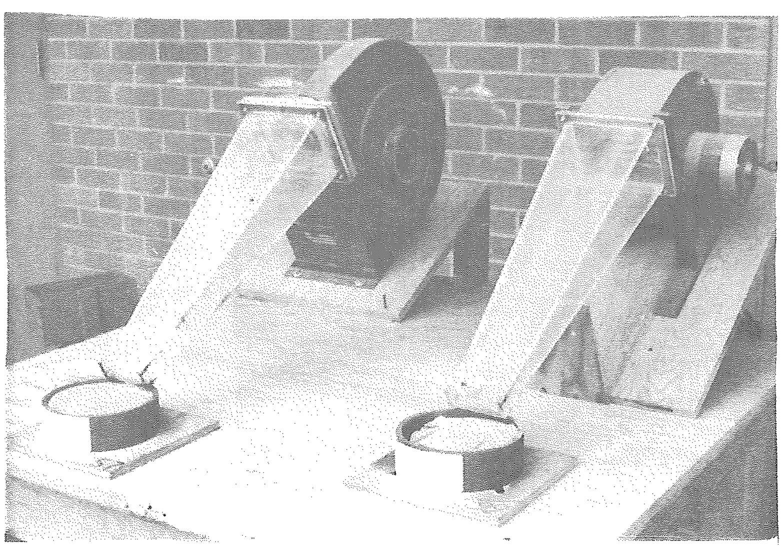

FIGURE 7: WIND BLOWER TEST SET UP

a wind velocity of 45 mph using the small blower and a wind velocity of 90 mph using the larger blower. A test period of 3 minutes was selected since it was more than the time required for water-sprayed specimens to completely erode away.

7. At the end of the wind test period, each specimen was reweighed and the difference from the weight after curing was considered as weight of sand particles eroded away by wind. A small sample was taken at the end of the wind test to determine the moisture content. The moisture content was used to correct the amount of sand loss to a dry-weight basis. The ratio of this corrected weight loss to the original weight of the dry sand placed in the mold (1435 gms) in percent, was considered as the "erosion percent".
8. Duplicate specimens were tested for each test condition, and the resulting average erosion percent was reported as the corresponding value for the particular specimen condition.

Test Results

The results of this wind erosion test are summarized in Table 3 and include the chemical name and the erosion percent under 45 mph and 90 mph wind velocities for specimens cured for 1, 3, and 7 days. Also included is the cost of chemical application per square yard. This cost refers to the cost of the chemical only; F.O.B. the location of the manufacturer or supplier. Later on in the report both chemical costs (F.O.B. supplier and F.O.B. Tucson, Arizona) are reported for selected chemicals. The rates of application used in this test are given in summary sheets for the chemicals in Appendix B, along with the depths of penetration observed in each case. It is pointed out that the thickness of the surface crust developed after curing did not necessarily equal the depth of penetration observed at the application. In most cases the full 2 inch thickness of the specimen was moist after the spraying application, but the cured crust thickness ranged from 1/8 inch to 3/4 inch. Figure 8 displays two crusts for two different chemicals. The mode of failure of most specimens that did not withstand the wind was due to break up of the surface crust and a subsequent rapid erosion of the loose sand below. For such behavior, specimens are marked "F" in Table 3 to denote failure.

TABLE 3: WIND EROSION TEST RESULTS (Sand, 70°F Curing)

Chem. No.	Chemical Name	Erosion, Percent						Cost ¢/yd^2 F.O.B. Supplier
		45 mph			90 mph			
		1-day	3-day	7-day	1-day	3-day	7-day	
0	Water	0.23	3.21	F	1.60	F	F	--
1	Soil Stabilizer 801	0.07	0.07	0.0	5.27	0.07	0.0	11.6
2	Compound SP-301	0.0	0.0	0.0	0.0	0.07	0.0	10.4
3a	White Soil Stabilizer	0.0	0.0	0.0	0.0	0.0	0.21	5.2
3b	White Soil Stabilizer	0.0	0.0	0.0	0.0	0.0	0.0	10.3
4	Stikvel P-65	0.0	0.0	0.0	F	F	F	15.0
5	Velsicol W-617	0.0	0.0	0.0	F	F	F	14.6
6	Redicote E-52	Not Recommended by Supplier						
7	Aerospray 70	0.0	0.0	0.0	0.0	0.0	0.0	11.4
8	Aerospray 52	0.0	0.0	0.0	0.0	0.0	0.0	13.0
9	Curasol AE	0.0	0.0	0.0	0.0	0.0	0.0	12.4
10a	Polyco 2190	0.0	0.0	0.0	0.0	0.0	0.0	14.5
10b	Polyco 2190	0.0	0.0	0.0	0.0	0.0	0.0	14.5
11a	Polyco 2460	0.0	0.0	0.0	0.0	0.0	0.0	14.5
11b	Polyco 2460	0.0	0.0	0.0	0.0	0.0	0.0	14.5

TABLE 3 - Continued

Chem. No.	Chemical Name	Erosion, Percent						Cost ¢/yd^2 F.O.B. Supplier
		45 mph			90 mph			
		1-day	3-day	7-day	1-day	3-day	7-day	
12	Orzan GL-50	0.0	0.0	0.0	0.0	0.0	0.0	3.3
13	Surfaseal	0.0	0.0	0.0	0.0	0.0	0.0	13.3
14a	Formula 125	F	F	F	F	F	F	10.8
14b	Formula 125	F	F	F	F	F	F	12.2
15	Enzymatic SS-1	Not Recommended by Supplier						
16a	RTD-SS-X	0.14	0.07	44.0	2.8	F	F	0.8
16b	RTD-SS-X	0.14	8.3	F	28.5	F	F	1.6
17	Norlig-41	0.0	0.0	0.0	0.0	0.0	0.0	4.0
18	Dust Bond 100	0.0	0.0	0.0	0.0	0.0	0.0	12.0
19	Sodium Silicate #9	0.0	0.0	0.0	0.0	0.0	0.0	5.0
20a	Petroset SB	0.0	0.0	0.0	0.0	0.0	0.0	11.5
20b	Petroset SB	0.0	0.0	0.0	0.0	0.0	0.0	14.0
21a	Coherex	0.0	0.0	0.0	0.0	0.0	0.0	2.9
21b	Coherex	0.0	0.0	0.0	0.0	0.0	0.0	4.6
21c	Coherex	0.0	0.0	0.0	0.0	0.0	0.0	6.9
21d	Coherex	0.07	0.0	0.0	0.07	0.07	0.0	7.5
22	Soiltex	0.0	0.0	0.0	0.0	0.0	0.14	5.0

TABLE 3 - Continued

Chem. No.	Chemical Name	Erosion, Percent						Cost ¢/yd^2 F.O.B. Supplier
		45 mph			90 mph			
		1-day	3-day	7-day	1-day	3-day	7-day	
23	Thermoset 401	Not Recommended by Supplier						
24	Enzymatic SS-2	Not Recommended by Supplier						
25	Dresinate DS-60W-80F	0.0	0.0	0.0	0.0	0.0	0.0	8.5
26	Paracol 1461	0.0	0.0	0.0	0.0	0.0	0.0	9.8
27	Terrakrete #2	0.0	0.0	0.0	0.0	0.0	0.0	11.1
28	Terrakrete #1	0.0	0.0	0.0	0.14	0.0	6.21	3.0
29a	M-Binder	Too Viscous to Spray						9.3
29b	M-Binder	0.0	0.0	0.0	2.23	F	F	9.3
30	Triton X-114SB	0.0	0.0	0.0	0.0	0.0	12.47	5.9
31	Corexit 7740	0.35	F	F	6.76	F	F	0.1
32	Super Crete-100	0.21	0.0	0.0	F	0.14	5.78	8.0
33	Aliquat H226	F	2.93	30.52	F	F	F	11.0
34	Petroset RB	Too Viscous to Spray						
35	Biobinder	0.0	0.0	0.0	0.0	0.0	0.0	12.0
36	Surfax 5107	0.35	5.59	F	0.21	F	F	0.45
37a	Dust Control Oil	0.0	0.0	0.0	0.0	0.0	0.0	7.5
37b	Dust Control Oil	0.0	0.0	0.0	0.0	F	F	3.8

TABLE 3 - Concluded

Chem. No.	Chemical Name	Erosion, Percent						Cost‡ ¢/yd² F.O.B. Supplier
		45 mph			90 mph			
		1-day	3-day	7-day	1-day	3-day	7-day	
38	Dust Stop	0.0	0.0	0.0	0.0	0.0	0.0	7.9
39	Aquatain (Liquid)	0.0	0.0	0.0	0.0	0.0	0.0	8.8
40	Aquatain (Powder)	0.0	0.0	0.0	0.0	0.0	0.0	5.2
41	Foramine 99-194	0.0	0.0	0.0	0.0	0.0	0.0	13.6
42	Plyamul 40-153	0.0	0.0	0.0	0.0	0.0	0.0	12.4
43	Ashland Oil Stabilizer	0.0	0.0	0.0	F	F	F	15.0
44	Compound SP-400	0.0	0.0	0.0	0.0	0.0	0.0	11.0
45	Foramine 99-434-2	0.0	0.0	0.35	0.0	0.72	0.0	14.0
46	Norlig-41 + F.125	0.0	0.0	0.0	0.0	0.0	0.0	9.1

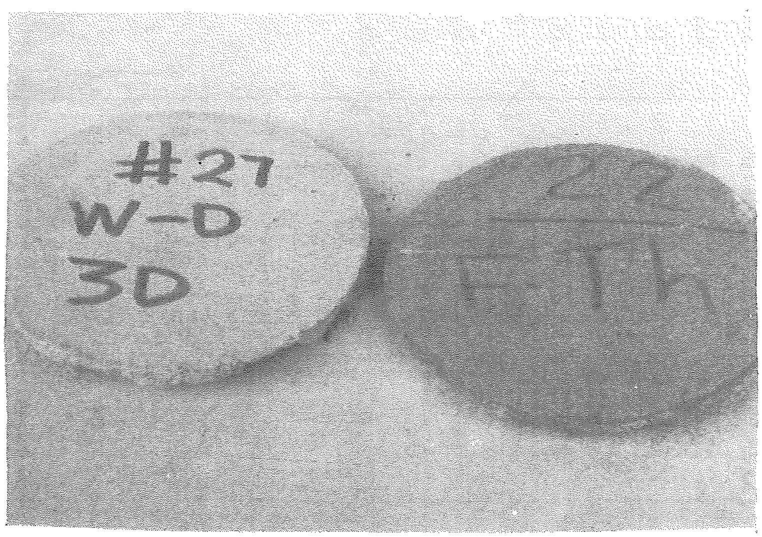

FIGURE 8: SURFACE CRUST OF SPRAYED-ON SAND SPECIMENS

Discussion of Test Results

The results given in Table 3 indicate that many of the chemicals applied were quite effective in reducing or eliminating erosion of the dune sand under wind velocities of up to 90 mph. Four of the chemicals available were not recommended by their manufacturers for use with wind erosion studies, these are: Redicote E-52, Enzymatic SS-1, Thermoset 401, and Enzymatic SS-2. Accordingly the data for these chemicals are not reported even though some were successful in eliminating wind erosion losses.

Twenty-seven chemicals were selected based on their performance in this test to undergo further testing to evaluate the durability of their stabilization potential after being subjected to adverse environmental conditions. It is pointed out that, at this stage in the study, the manufacturer of chemical No. 10 (Polyco 2190) advised us that the chemical has been discontinued and no additional supply was available for any further testing. The durability tests included freeze-thaw cycles, wet-dry cycles, rain-dry cycles and variation of curing temperatures. These tests are discussed below.

Environmental-Durability Tests

For these tests the sand samples were cured for 3 days, subjected to the durability test specified and then tested under wind velocities of 45 and 90 mph. Most of the durability tests caused an increase in the moisture contents of the specimens, therefore, at the end of the durability testing the specimens were allowed to air-dry to constant weight before being subjected to wind tests. This procedure was adopted to test the wind erodibility at the dry state which is most vulnerable to wind erosion, without the additional stabilizing effect of capillary moisture.

Freeze-Thaw Cycles

1. Specimens were prepared and sprayed with the chemicals as described before.
2. Specimens were allowed to cure for 3 days in the environmental room (70°F, 50% R.H.).

3. Specimens were then placed for 6 hours in a 70°F, humid room where access to moisture was available through the continuous moisture spray and vapor in the humid room. No direct impact of water spray was allowed on the specimens. This procedure was used in lieu of placing the specimens on moist pads which was difficult to attempt since the sand in the molds was quite loose below the surface.
4. Specimens were subjected to 3 freeze-thaw cycles. Each cycle consisted of 6 hours in a freezing room at 10°F and 18 hours in a 70°F humid room. At the end of the third cycle each specimen was allowed to air-dry in the environmental room to a constant weight, which was recorded.
5. Duplicate specimens were tested under 45 mph wind velocity and another set was tested under 90 mph, as described before. The weight of the specimen was recorded after the wind test and any loss was recorded. A final water content sample was taken to determine the moisture content after the wind test and to correct the amount of erosion loss to a dry weight basis. For each specimen, the ratio of this corrected weight loss to the original dry weight of the sand in percent was calculated and the average value was reported as the erosion percent.

Wet-Dry Cycles

1. Specimens were prepared and sprayed with the chemicals as described before.
2. Specimens were allowed to cure for 3 days in the environmental room (70°F, 50% R.H.).
3. Specimens were then subjected to 3 wet-dry cycles. Each cycle consisted of 6 hours in a 70°F humid room and 18 hours in the environmental room. At the end of the third cycle each specimen was left in the environmental room to dry out to a constant weight, which was recorded.
4. Duplicate specimens were tested under 45 mph wind velocity and another set was tested under 90 mph, as described before. The weight of each specimen was recorded after the wind test and

any loss was recorded. A final water content sample was taken to determine the moisture content after the wind test and to correct the amount of erosion loss to a dry weight basis. For each specimen, the ratio of this corrected weight loss to the original dry weight of the sand in percent was calculated and the average value was reported as the erosion percent.

Rain-Dry Cycles

The machine used to simulate rainfall is known as the "Rotadisk Rainulator". The Rainulator gives a combination of relatively low intensity rain (varying from close to zero to more than 60 inches per hour) with realistic drop sizes and high impact velocity. This is accomplished through the use of a pressure controlled high capacity nozzle and slotted-rotating disks to regulate the impact velocity and intensity. The Rainulator was built in 1971 at the Civil Engineering Department based upon the original drawings by Morin et al (1970) as modified by Sultan (1971). The operational principals of the Rainulator have been presented previously elsewhere, and a summary is given in Appendix C.

In this study an average rain intensity of 2.38 inches per hour was used. The specimens were placed on a 14° slope with the horizontal; this slope was chosen based on previous studies which indicated this slope to cause high erosion amounts, El-Rousstom (1973). The procedure followed for this test is described below.

1. Specimens were prepared and sprayed with the chemicals as described previously.
2. Specimens were allowed to cure for 3 days in the environmental room (70°F, 50% R.H.). After this curing period the weights were recorded.
3. Specimens were then subjected to 3 rainfall-dry cycles. Each cycle consisted of 1 hour of rain at 2.38 inches per hour and 23 hours in the environmental room (70°F, 50% R.H.). Figure 9 shows specimens being tested in the rainfall simulator.
4. At the end of the third cycle, each specimen was left in the environmental room to dry out to a constant weight, which was then recorded. This period was usually about 3 days.
5. Duplicate specimens were then tested under 45 mph wind velocity

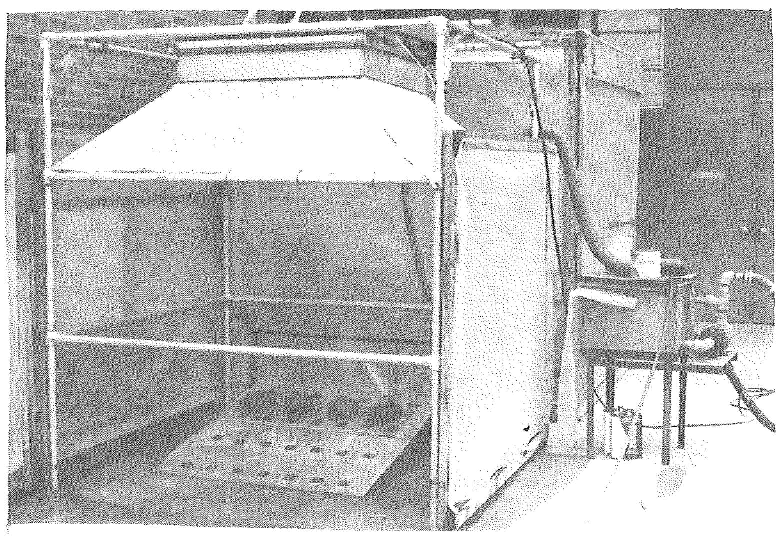

FIGURE 9: ROTATING DISK RAINFALL SIMULATOR

and another set was tested under 90 mph, as described previously. The weight of the specimen was recorded after the wind test and any loss was recorded. A final water content sample was taken to determine the moisture content after the wind test and to correct the amount of erosion loss to a dry weight basis. The ratio of the corrected weight loss during the wind test to the original dry weight of the sand in percent is the erosion percent due to wind. The corrected weight loss during the 3 rainfall-dry cycles presented as a ratio of the original dry weight of the sand is the erosion percent due to rain. Both values are reported as described later on under "Test Results".

Variation of Curing Temperature

Since the environmental room temperature of 70°F was generally used for the curing of the test specimens, it was decided to evaluate the effect of temperature during curing on the wind erosion control capability of the cured specimens. This test was conducted as follows:

1. Specimens were prepared and sprayed with the chemicals as described before.
2. One group of specimens was allowed to cure for 3 days in a controlled environment of 40°F at 50% R.H. At the end of the curing period the weights of the specimens were recorded.
3. Another identical group of specimens was allowed to cure for 3 days in a closet-size convection oven with temperature ranging between 140°F-145°F as measured continuously by thermometers. At the end of the curing period the weights of the specimens were recorded.
4. Duplicate specimens from each group were tested under 45 mph wind velocity, and another set was tested under 90 mph, as described previously. The weight of each specimen was recorded after the wind test and any loss was recorded. A final water content sample was taken to determine the moisture content after the wind test and to correct the amount of erosion loss to a dry weight basis. For each specimen, the ratio of this corrected weight loss to the original dry

weight of the sand in percent was calculated and the average value was reported as the erosion percent.

Test Results

The results of the wind erosion tests on specimens subjected to the various environmental-durability conditions described above, are presented in Table 4. Separate listings are given for tests conducted at 45 mph and at 90 mph wind velocities. The erosion percent values reported pertain to the corrected soil loss during the wind tests. In the rain-dry cycles, both the erosion percent due to wind and the erosion percent experienced during the 3 cycles are reported; the first number refers to the former while the second number refers to the latter, respectively.

Discussion of Test Results

Out of the 27 chemicals selected for this phase of the testing program 20 chemicals appeared to successfully endure the various environmental conditions to which they were subjected and afford a good measure of wind erosion control under the test conditions.

As discussed previously, the cost of the chemical treatment for all these chemicals was held at a cost below 15 cents per square yard. However, due to the large number of chemicals passing the tests performed, it was decided to look into the possibility of reducing the cost of the chemicals to about one-half that amount. This was also in agreement with the cost figures being looked at during this time by the Property Management Division of the Arizona Department of Transportation.

It is pointed out that based on the results given in Table 4, the rain-dry cycles proved to be the most severe type of durability test since it generally resulted in higher erosion than the other environmental-durability conditions.

Wind Erosion Tests-Reduced Rates

As discussed above, the amount of sprayed-on chemical was reduced such that the cost of the chemical treatment will not exceed 7.5 cents per square yard (cost of chemicals FOB suppliers). This was achieved through the reduction of the application rate, increasing the dilution ratio, or both. The dilution rates and the rates of application of the

TABLE 4: WIND EROSION AFTER DURABILITY TESTS (Sand, 3-day Cure)

Chem. No.	Chemical Name	Erosion Percent, at 45 mph						Cost ¢/yd^2 F.O.B. Supplier
		40°F	70°F	140°F	Fr-Th	Wet-Dry	Rain-Dry	
0	Water	0.07	3.21	F	F	F	F-46.8	--
2	Compound SP-301	0.0	0.0	0.42	0.56	0.0	9.8-16.5	10.4
3b	White Soil Stabilizer	0.0	0.0	0.28	0.14	0.0	1.2-40.3	10.3
7	Aerospray 70	0.0	0.0	0.0	0.0	0.0	0.0- 0.8	11.4
8	Aerospray 52	0.0	0.0	0.0	0.0	0.0	0.0- 2.56	13.0
9	Curasol AE	0.0	0.0	0.0	0.0	0.0	0.07-7.04	12.4
11b	Polyco 2460	0.0	0.0	0.0	0.0	0.0	0.07-2.85	14.5
12	Orzan GL-50	0.0	0.0	0.0	0.0	0.0	0.21-26.5	3.3
13	Surfaseal	0.0	0.0	0.0	0.0	0.0	0.0- 2.65	13.3
17	Norlig-41	0.0	0.0	0.0	0.0	0.0	3.48-25.5	4.0
18	Dust Bond 100	0.0	0.0	0.0	0.0	0.0	6.2-36.1	12.0
19	Sodium Silicate #9	0.0	0.0	0.0	0.0	0.0	0.56-8.22	5.0
20a	Petroset SB	0.0	0.0	0.0	0.0	0.0	0.0-1.95	11.5
21a	Coherex	0.0	0.0	0.0	0.0	0.0	0.0-12.5	2.9
21c	Coherex	0.0	0.0	0.14	0.07	0.07	0.14-13.2	6.9
22	Soiltex	0.0	0.0	0.0	0.0	0.0	0.21-25.3	5.0

TABLE 4 - Continued

Chem. No.	Chemical Name	Erosion Percent, at 45 mph						Cost ¢/yd^2 F.O.B. Supplier
		40°F	70°F	140°F	Fr-Th	Wet-Dry	Rain-Dry	
25	Dresinate DS-60W-80F	0.0	0.0	0.0	0.0	0.0	0.0-26.6	8.5
26	Paracol 1461	0.0	0.0	0.21	0.0	0.0	0.14-1.12	9.8
27	Terrakrete #2	0.0	0.0	0.0	0.0	0.0	0.07-18.4	11.1
35	Biobinder	0.0	0.0	0.0	0.0	0.0	0.14-17.6	12.0
37a	Dust Control Oil	0.0	0.0	0.0	0.07	0.0	0.0- 2.3	7.5
37b	Dust Control Oil	0.0	0.0	0.0	0.07	0.0	0.0- 10.5	3.8
38	Dust Stop	0.0	0.0	0.0	0.0	0.0	0.0- 8.64	7.9
39	Aquatain (Liquid)	0.14	0.0	0.0	22.3	0.0	F -28.9	8.8
40	Aquatain (Powder)	0.07	0.0	0.0	0.14	0.0	0.0-19.1	5.2
41	Foramine 99-194	0.0	0.0	0.0	0.0	0.09	0.0- 8.2	13.6
42	Plyamul 40-153	0.0	0.0	0.0	0.0	0.0	0.0- 0.76	12.4
44	Compound SP-400	0.0	0.0	0.0	0.0	0.0	0.0- 3.28	11.0
45	Foramine 99-434-2	0.21	0.0	0.0	0.0	0.0	0.14-20.1	14.0
46	Norlig 41 + F125	0.0	0.07	0.0	0.0	0.0	0.14-0.52	9.1

TABLE 4 - Continued

Chem. No.	Chemical Name	Erosion Percent, at 90 mph						Cost ¢/yd^2 F.O.B. Supplier
		40°F	70°F	140°F	Fr-Th	Wet-Dry	Rain-Dry	
0	Water	3.07	F	F	F	F	F -48.2	--
2	SP-301	F	0.07	F	F	9.62	35.8-17.3	10.4
3b	White Soil Stabilizer	0.0	0.0	0.56	0.63	0.0	9.76-39.4	10.3
7	Aerospray 70	0.0	0.0	0.0	0.0	0.0	0.14- 0.6	11.4
8	Aerospray 52	0.0	0.0	0.0	0.0	0.0	0.07-2.41	13.0
9	Curasol AE	0.0	0.0	0.0	0.0	0.0	0.14-8.34	12.4
11b	Polyco 2460	0.10	0.0	0.0	0.0	0.0	0.0- 3.28	14.5
12	Orzan GL-50	0.0	0.0	0.07	0.07	0.0	6.27-24.6	3.3
13	Surfaseal	0.0	0.0	0.25	0.07	0.15	0.21-2.41	13.3
17	Norlig-41	0.0	0.0	0.0	0.0	0.0	11.85-26.2	4.0
18	Dust Bond 100	0.0	0.0	0.0	0.14	5.8	47.87-35.9	12.0
19	Sodium Silicate #9	0.0	0.0	0.0	0.0	0.28	14.15-8.78	5.0
20a	Petroset SB	0.0	0.0	0.0	0.0	0.0	0.07-2.15	11.5
21a	Coherex	0.0	0.0	0.0	0.0	0.0	0.0-13.2	2.9
21c	Coherex	0.0	0.0	0.14	0.07	0.21	0.21-14.3	6.9
22	Soiltex	0.0	0.0	0.21	0.74	1.14	22.72-23.5	5.0
25	Dresinate DS-60W-80F	0.0	0.0	0.0	0.0	0.0	0.63-28.2	8.5

TABLE 4 - Concluded

Chem. No.	Chemical Name	Erosion Percent, at 90 mph						Cost ¢/yd^2 F.O.B. Supplier
		40°F	70°F	140°F	Fr-Th	Wet-Dry	Rain-Dry	
26	Paracol 1461	0.21	0.0	0.21	0.0	0.07	0.21-1.23	9.8
27	Terrakrete #2	0.0	0.0	0.0	0.0	0.0	0.21-17.0	11.1
35	Biobinder	0.0	0.0	0.0	0.0	0.0	44.4-16.5	12.0
37a	Dust Control Oil	0.07	0.0	0.0	0.07	0.0	0.07-2.9	7.5
37b	Dust Control Oil	0.0	F	F	F	F	0.0- 11.2	3.8
38	Dust Stop	0.07	0.0	0.21	0.0	0.0	0.0-8.85	7.9
39	Aquatain (Liquid)	0.21	0.0	0.14	F	0.0	F -28.4	8.8
40	Aquatain (Powder)	0.28	0.0	0.49	0.21	0.0	0.14-19.2	5.2
41	Foramine 99-194	0.07	0.0	0.0	0.0	0.14	0.07-7.9	13.6
42	Plymul 40-153	0.07	0.0	0.0	0.0	0.0	0.0- 0.78	12.4
44	Compound SP-400	0.0	0.0	0.0	0.0	0.0	0.0- 3.62	11.0
45	Foramine 99-434-2	0.70	2.72	0.0	0.0	0.28	0.49-19.2	14.0
46	Norlig 41 + F125	0.0	0.07	0.0	0.0	0.07	0.28-0.55	9.1

chemicals at the reduced rates are outlined in the Summary Sheets given in Appendix B. In addition to the 20 chemicals that successfully passed the environmental tests, four additional chemicals that did not actually perform too well were also included for the new testing using the reduced rates. These four chemicals are Dust Bond 100, Sodium Silicate #9, Soiltex, and Dust Control Oil. Dust Bond 100 and Soiltex were added to compare their results with other lignin-sulfonate based products. Dust Control Oil was added since at that time a field test was monitored by the principal investigator for the Property Management Division of ADOT and the results of that test indicated a high degree of dust control using this chemical; Sultan (1974). Sodium Silicate #9 was added since it passed all the tests except the rain-dry cycles.

Test Procedures - Reduced Rates

The test procedures outlined previously for the wind erosion test, the freeze-thaw cycles, the wet-dry cycles, the rain-dry cycles, and the variable curing temperature tests were followed for the specimens sprayed with the reduced rates of chemicals. The only difference was that only one set of specimens was used and tested at 90 mph only. The 45 mph set was not conducted due to time limitations and since the 90 mph test was more severe anyway.

Test Results - Reduced Rates

The wind erosion results of the reduced-rate specimens subjected to the various environmental-durability conditions are presented in Table 5. The erosion percent reported pertains to the corrected soil loss during the wind test. Under the rain-dry cycles two values of erosion percent are reported, the first is due to wind erosion, the second is due to rain erosion, respectively.

Discussion of Test Results

Out of the 24 chemicals used in the reduced-rate tests, 14 chemicals appeared to successfully endure the various environmental conditions to which they were subjected and afford a good measure of wind erosion control under the test conditions at 90 mph wind velocity. A selection criterion was arbitrarily set that eliminates any chemical treatment that resulted in an erosion percent due to wind equal to or greater than